Crystal vs. melt compositional effects on the partitioning of the first-row transition and high field strength elements between clinopyroxene and silicic, alkaline, aluminous melts

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ABSTRACT

The first-row transition element (FRTE) and high field strength element (HFSE) systematics are powerful tools for tracking the source and evolution of mantle-derived magmas. Clinopyroxene is generally considered a key fractionating mineral controlling the partitioning of trace elements between melt and residual solid during mantle melting. Although partitioning of FRTE and HFSE between clinopyroxene and basaltic melts has been well-studied, experimental constraints on their partitioning behavior in the presence of siliceous, aluminous, and alkali-rich melts are still lacking. Here we present clinopyroxene-silicic melt (67–69 wt% SiO2) partitioning experiments at 1 bar pressure and 1070–1100 °C for Co, Mn, Ni, Cu, Zn, Fe, Sc, Cr, V, Ti, Zr, Hf, Nb, and Ta. Run products consist of diopside clinopyroxene coexisting with various melt compositions with non-bridging oxygen to tetrahedral cation ratio (NBO/T) ranging from 0.10 to 0.22. Using our new partition coefficients (Ds) and combined with literature data, we assess some of the effects of crystal chemistry and the melt composition on the partitioning of FRTE and HFSE in this simple system.

We show that partitioning of FRTE varies from mildly incompatible (e.g., D = ~0.1–1 for V, Cu, and Zn) to highly compatible (e.g., D > 10 for Cr and Ni), with the highest compatibilities observed for Ni (D Ni = 13–34). The partitioning of HFSE varies from highly incompatible (D = 0.01–0.08) for Nb and Ta to mildly incompatible (D = 0.18–0.82) for Zr, Hf, and Ti. Our measured clinopyroxene-melt Ds are consistent with the theoretical predictions of the lattice strain model. Ds data for most trivalent, tetravalent, and pentavalent elements tend to increase with increasing tetrahedrally coordinated Al content, in agreement with those anticipated from crystal-chemical considerations. In contrast to Al concentrations, the clinopyroxene Na concentration has very little effect on trace element partitioning due to its low concentrations in clinopyroxene at relatively low-pressure conditions. These data further support a significant control of melt composition/structure on partitioning for highly polymerized melts. In general, measured Ds roughly increase to different extents with increasing polymerization of the melt (i.e., lower NBO/T or higher ASI). For our equilibrium melt compositions, Ds for several FRTE, such as Co and Ni, correlate well with the melt molar Mg2+/M2+/(M2+ + M3+), whereas Ds for HFSE vary as a function of the melt alkali concentration. These well-defined trends support the role of melt NBO species (e.g., Mg2+) or complexing ligands (e.g., Na+ and K+) in controlling the partitioning of these elements.

Overall, our new Ds data demonstrate that even very small changes in melt major-element compositions can greatly affect element partitioning in strongly polymerized silicic systems. These findings have important implications relevant to petrogenetic studies of the interaction between silicic melt and peridotite that occurs at shallow mantle conditions in various tectonic settings.

Keywords: Clinopyroxene, melt composition, FRTE, HFSE, partition coefficient

INTRODUCTION

Siliceous, alkali-rich and aluminous glasses have been widely reported in mantle-derived spinel peridotite xenoliths from various geographic and tectonic localities (e.g., Xu et al. 1996; Vannucci et al. 1998; Yaxley and Kamenetsky 1999; Miller et al. 2012), including continental alkali basalt provinces, oceanic hot spots, and subduction-related settings. The glasses contain from 40 to >70 wt% SiO2, up to 17 wt% total alkalies, and up to 25 wt% Al2O3 (Yaxley and Kamenetsky 1999). As a result, the interaction between peridotite and such silicic melts has received considerable attention as an effective mechanism of mantle metasomatism (e.g., Coltorti et al. 2000; Qian et al. 2015), which may contribute to the heterogeneous enrichment of erupted lavas. In particular, phase-equilibrium experiments further show that these kinds of melts can be readily in equilibrium with harzburgitic or lherzolitic mineral assemblages at low pressures (Draper and Green 1997, 1999). Knowledge of element partitioning between mantle minerals and silicic, alkaline, aluminous melts is therefore pivotal to understanding upper mantle processes such as equilibrium partial melting and metasomatism.

Clinopyroxene (Cpx) is a common mineral in upper mantle